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EVALUATION OF DRAGER TUBES FOR MOISTURE DETERMINATION

V.P. Singh
Engineer, Process Development
Process Chemistry Section
Chemical Research Department
Report No 86-338-K

ABSTRACT

Two types of Drager tubes suitable for low and high ranges of dew point were evaluated experimentally. Accuracies of $\pm 2^{\circ}C$ were obtainable and the results supported the manufacturer's claims. The tubes were not adversely affected when used in a hydrogen atmosphere.

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EXECUTIVE SUMMARY

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V.P. Singh
Process Chemistry Section
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The electrical power generators of Ontario Hydro use hydrogen gas which aids in their cooling. Specifications call for generator shutdown if the dew point (d.p.) exceeds a given value, typically -10°C. Present methods of dew point measurement, eg, with Panametrics aluminum oxide sensors and Alnor hygrometers suffer the disadvantages of requiring calibration and maintenance and these problems may be avoided with the use of Drager tubes. The objective of the present work was to test the Drager tubes for accuracy.

The work commenced with a high range tube (lower detection limit -24°C with twenty strokes) and was repeated when a low range tube (lower detection limit -40°C with twenty strokes) became available. Gas of known water content in the range -35 to 0°C d.p. was generated by mixing measured quantities of dry (<-76°C d.p.) nitrogen and nitrogen saturated by passing through a bubbler (approximately 23°C d.p.). The generated dew point was checked with an optical chilled mirror hygrometer.

Individual tube readings with both the high and low range tubes used in this study generally indicated dew points with a ±2°C accuracy. Graphs are presented allowing estimation of the upper and lower limits of the dew point as a function of the number of tubes used in the determination and the desired confidence level. The major advantage of the low range tube is its capability to measure lower dew points than the high range tube. A disadvantage is the use of magnesium perchlorate which requires additional safety precautions. Tests on both high and low range tubes showed no undesirable effect of hydrogen gas.

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To: Dr. D. Mills
Director of Research

EVALUATION OF DRAGER TUBES FOR MOISTURE DETERMINATION

V.P. Singh

1.0 BACKGROUND

The electrical power generators of Ontario Hydro use hydrogen gas which aids in their cooling. The enclosed hydrogen atmosphere is isolated from ambient air to maintain it outside flammability limits. In addition, attempts are made to exclude water to maintain the insulating properties of the gas. Presently, specifications call for generator shutdown if the dew point (d.p.)* measured at atmospheric pressure exceeds a given value, typically -10°C. Determination of the water vapour content in the hydrogen atmosphere has been carried out with Panametrics dew point meters but their accuracy is questionable/1/. Alnor dew point meters are also used but these require occasional maintenance and significant time for purging for accurate low dew point determinations because of the volume of the instrument and the long line required to deliver gas to the instrument. The Alnor instrument also requires a trial and error procedure for the determination and operator experience affects the accuracy of the result. The use of Drager tubes for water vapor determination avoids uncertainties as to recalibration and maintenance intervals and rapid measurements appear possible, eg, for checking other instruments. Their use has been initiated by Pickering Nuclear Generating station and confidence has been increasing on the reliability of the determination. The objective of the present work was to test the Drager tubes for accuracy and reproducibility in the laboratory.

1.1 Water Detection Tubes

The detector tube measuring unit consists of the detector tube and the corresponding pump/2/. The pump consists of a bellows arrangement with an inlet port for the detector tube at which there is a check valve. This valve prevents reverse flow through the detector tube when the bellows is compressed. Operation is carried out by fully compressing the bellows by hand and when released the bellows sucks in a volume of gas through the detector tube. This procedure is equivalent to one stroke after the bellows attains its fully expanded position. The gas volume is thus metered during this process (100 mL per stroke).

* All values below 0°C refer to frost point rather than dew point.

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Properties of the Drager tubes for water detection are summarized in Table 1. The only water detection tube available at the start of this study had a measurement range of 1 to 40 mg H_2O/L* (approximately -17°C to +34°C dew point at atmospheric pressure) with ten strokes of the bellows pump. If twenty strokes are used, the indication must be divided by two. The lower detection limit then becomes 0.5 mg/L or -24.2°C d.p.. Lower concentrations, eg, 0.1 mg H_2O/L or -39.5°C d.p. can be estimated only. Use of more than twenty strokes is not indicated by Drager. The tube is recommended for short-term tests of total duration less than ten minutes. The reaction principle for the yellow to reddish brown colour change is described by:

$$H_2O + SeO_2^{**} + H_2SO_4 + \text{Reducing Agent} \rightarrow \text{Reddish Brown Selenium}$$

Since the testing of the above high range Drager tubes, we have been able to obtain recently developed/3/ Drager tubes with a normal measuring range (two pump strokes) of one to twenty mg/L (-17 to +22°C d.p.). The manufacturer claims even lower detection limits of 0.5 mg/L (-24.2°C d.p.) with four strokes of the pump, 0.2 mg/L (-33.3°C d.p.) with ten strokes and 0.1 mg/L (-39.5°C d.p.) with twenty strokes.

The colour change is from yellow to blue and the reaction with water is described by:

$$H_2O + Mg(ClO_4)_2 + \text{acid base indicator} \rightarrow \text{Turkish blue}$$

magnesium perchlorate	malachite green oxalate (a pigment)

The acid base indicator is yellow at very low pH values and appears to be a copper compound (carbonate, hydroxide, oxalate) which turns to blue when the pH is increased. The presence of perchlorate (approximately 10 mg/4/) although small in quantity and recommended by the manufacturer for use in methane, suggests that some care is required for use in hydrogen atmospheres. This is because magnesium perchlorate decomposes to produce oxygen above 250°C or when subjected to shock.

Additional data on the two tubes are presented in Appendix C. These were given by the manufacturer in the Drager Detector Tube Handbook, 6th edition and in the operating instructions supplied with the tubes. Also shown in Appendix C is a graph for converting the concentration indications (mg/L) to dew point (°C).

1.2 Accuracy of the Determination - High Range Tubes

The manufacturer claims a relative standard error of 15% due to random effects at the low end of the scale decreasing to 10% at the high end. Consider a large number of readings, ie, about thirty or more. This means that at the low end of the scale, 68% (one standard deviation, σ) of any large number of

---

* Litre at 20°C, 101.3 kPa (1 mg/L at 20°C = 1335 µL/L)

** The yellow colour may be due to SeO_3 since it is yellow while SeO_2 is white.

TABLE 1: PROPERTIES OF DRAGER TUBES FOR WATER DETECTION - MANUFACTURER'S CLAIMS

Number of Strokes (x)	Lower Detection Limit (LDL)		Upper Detection Limit (UDL)		Reading on Drager Tube Scale**	Divisor for Scale Reading $(x)/(n)$	Relative Standard* Error at LDL, UDL	
	Concentration (mg/L)	Dew Point (^{o}C)	Concentration (mg/L)	Dew Point (^{o}C)			(%)	^{o}C
High Range Tubes								
10 (=n)	1	-17	40	+34	1 40	1 1	15 10	1.5 2.0
20	0.5	-24.2	20	+22	1 40	2 2	Error limits not stated	
Low Range Tubes								
2 (=n)	1	-17	20	+22	1 20	1 1	30 25	3.5 5
4	0.5	-24	1.25	-15	1 2.5	2 2	- -	- -
6	0.33	-28	0.83	-19	1 2.5	3 3	- -	- -
10	0.2	-33	0.5	-24	1 2.5	5 5	- -	- -
20	0.1	-40	0.25	-31	1 2.5	10 10	- -	- -

* Standard deviation of concentration indications divided by average indication

** For concentrations $\leq$ 1 mg/L it is specified that the reading on the Drager tube scale be between 1 and 2.5.

readings will be within 15% of the true water vapor concentration and 95% (2σ) will be within 30%. In terms of dew point, 68% of the readings will be within 1.5°C at the low end and 2°C at the high end. Similarly, 95% of all readings will be within 3°C at the low end of the scale and within 4.5°C at the high end of the scale. However, it is also necessary to minimize other systematic errors due to tube deterioration during storage, improper gas sampling procedures, temperature changes, incorrect pump volume, interfering chemical species, etc.

In a practical situation, only a small number of readings are possible and statistical methods are necessary to establish accuracy of the readings (see Appendix D). Data from the manufacturer are used to generate Figure 1. It shows that if one tube is used to measure a -10°C dew point stream, readings in the range -6 to -18°C are possible 999 out of every 1000 times the sampling is done. Conversely, a reading with one tube of less than -18°C means that the dew point of the measured gas is less than -10°C for 999 out of every 1000 times. Similarly an average reading with two tubes of less than -15.5 means the dew point of the gas being measured is less than -10°C for 999 out of every 1000 times. The corresponding value for the average of five tubes is -13°C. Generally, more tubes should be used to determine the average as its value approaches the specification limit.

For example, suppose specifications call for a maximum dew point of -10°C. Suppose also that two tubes are used and an average reading of -15.5°C is obtained. Then, the dew point of the gas being measured lies in the range -10 to -19°C. There is a chance that this conclusion could be wrong once for every 1000 measurements, ie, that the dew point is above -10°C. If the dew point average of two tubes is greater than -15.5°C, then testing with a further three tubes may be carried out. If the average of the readings from five tubes is less than -13°C then the dew point of the measured stream is less than -10°C. If the average of the readings of the five tubes is greater than -13°C, then corrective action is recommended to reduce the dew point.

1.3 Accuracy of the Determination - Low Range Tubes

The manufacturer claims a relative standard error of 25 to 30% for the low range tubes when used in hydrogen atmospheres/5/. This high value is believed to be due to (i) the tubes having been developed for use on natural gas in which impurity levels can be significant and (ii) the limited experience with the recently developed tubes. Figure 2 may be used to determine the dew point range of any sampled stream from one to five individual determinations.

2.0 EXPERIMENTAL APPARATUS AND PROCEDURE

The apparatus used for testing the Drager tubes is shown in Figure 3. A series of tests was carried out to evaluate the Drager tubes at various water (H_2O) vapor contents in nitrogen. All the tests were carried out at ambient temperature (approximately 23°C) and pressure (approximately 760 mm Hg). Corrections for pressure whereby the true concentration is obtained by multiplying the scale indication by (101.3/atmospheric pressure in kPa) were generally small and were ignored. Gas streams with dew points of -0.8, -5.4, -6.9, -10.0, -15.7, and -20.8°C were generated by adjusting the flow controllers on the dry nitrogen and saturated nitrogen streams. Not all Drager tubes were tested at the above dew points. Combined flow rates of wet and dry gas ranged between 1.5 to 2.5 L/min. This exceeded the flow rate drawn by the

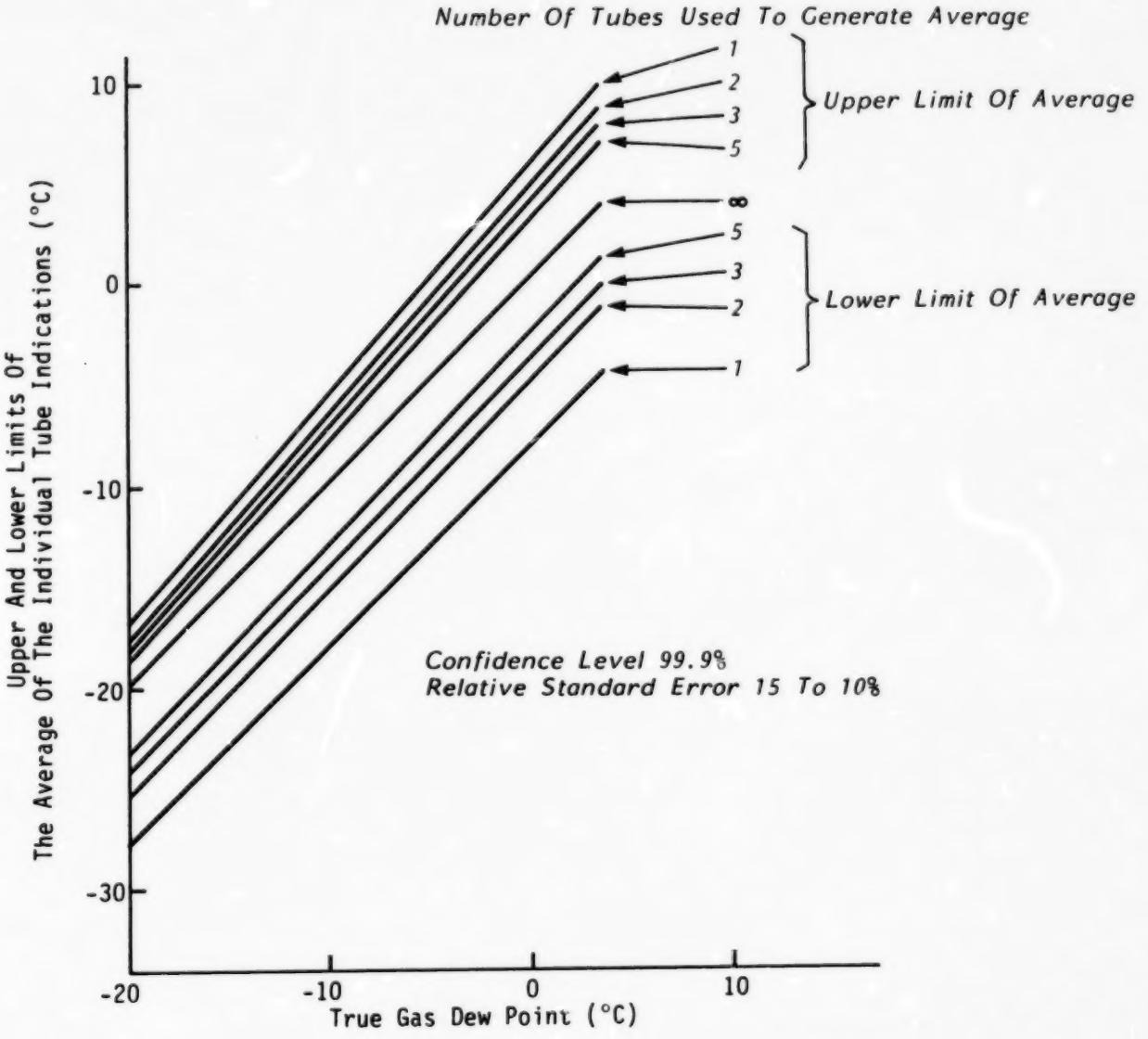

FIGURE 1

ACCURACY OF DRAGER INDICATION FOR ONE OR MORE DETERMINATIONS (HIGH RANGE TUBES) (POSSIBLY LOW RANGE TUBES, ALSO)

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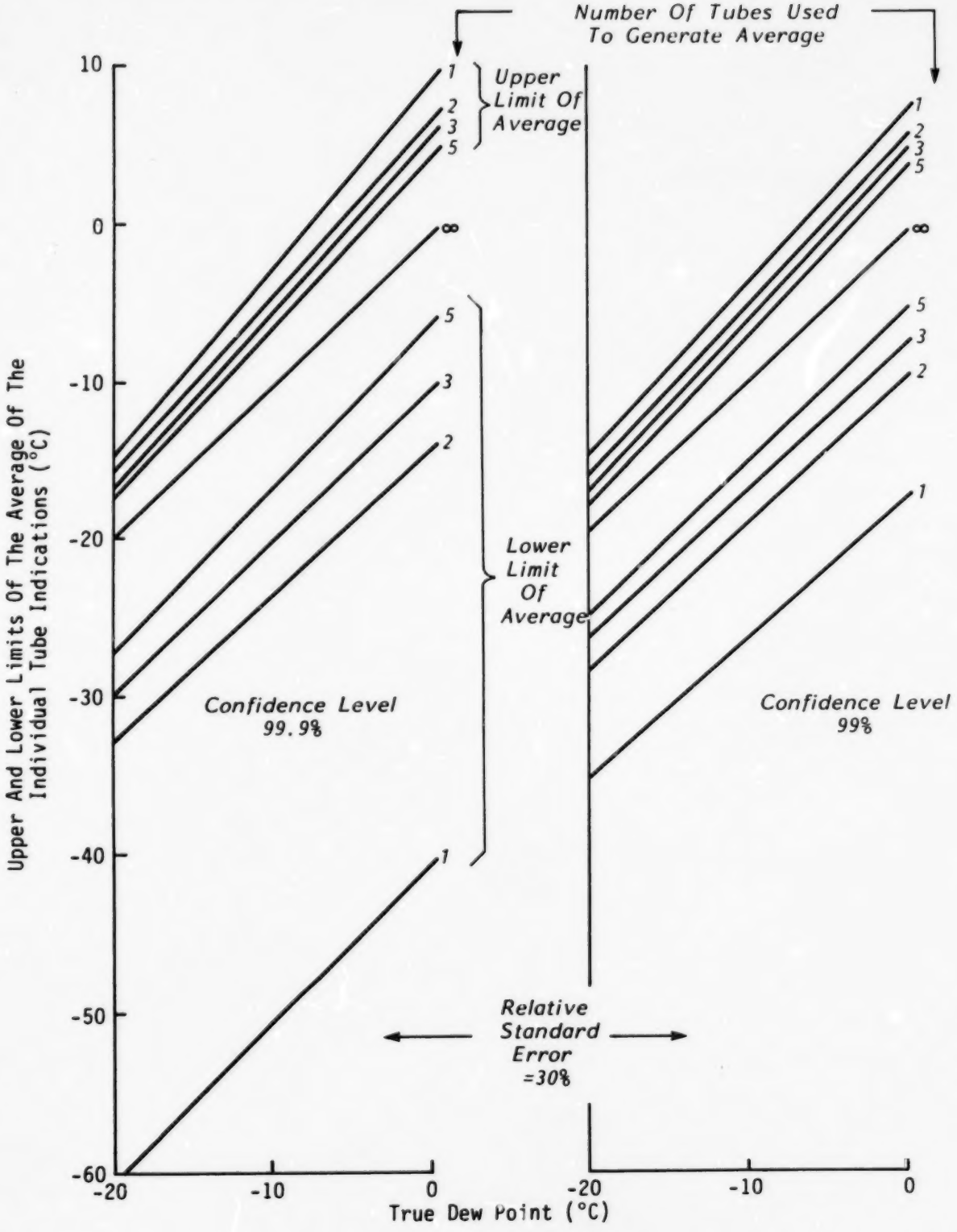

FIGURE 2

ACCURACY OF DRAGER INDICATION FOR ONE OR MORE DETERMINATIONS (LOW RANGE TUBES)

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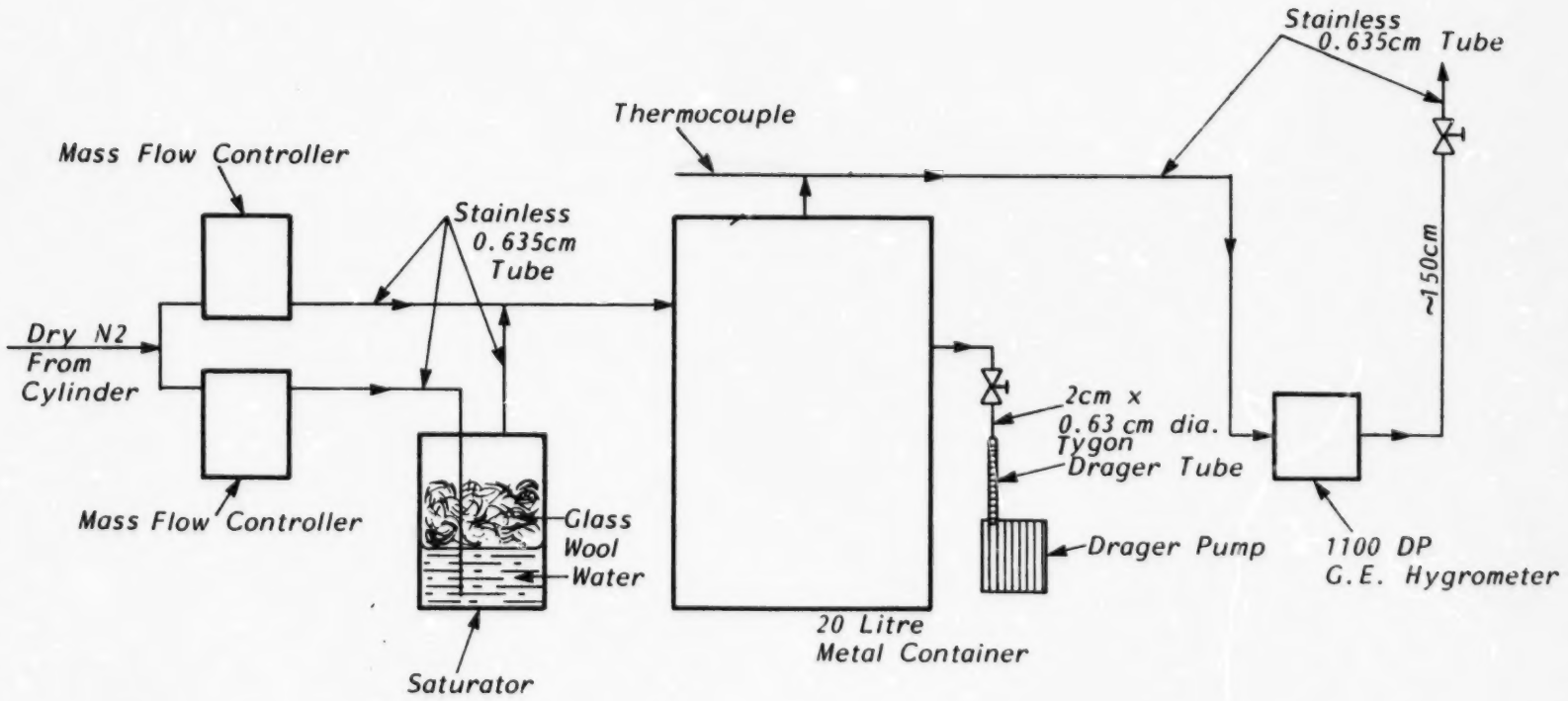

FIGURE 3

SCHEMATIC REPRESENTATION OF
EXPERIMENTAL APPARATUS

Drager batch pump of about 1.2 L/min and avoided sampling errors due to backflow. A General Eastern 1100DP Hygrometer (GE) was used to check the dew points. Precautions were taken to ensure that the instrument was controlling on frost rather than supercooled water by approaching the desired dew point from dew points less than -20°C. The Drager pump employed to sample the gas stream through the Drager tube was tested for leaks and stroke volume/1/. It was found to be leak free and the stroke volume was the required 100 mL.

The procedure for sampling was as follows. The sampling valve was opened partially and both the upstream and downstream tips of the detector tube were broken using the break off eyelet on the pump. The detector tube was immediately firmly inserted into the pump inlet connection and the sampling line. Care was taken to insert the tube such that the arrow printed on it pointed towards the pump. The sample was then drawn through the Drager tube. Several tubes were tested at each dew point and readings were taken of the discoloration length after a given number of strokes for each tube.

3.0 RESULTS AND DISCUSSION

3.1 High Range Tubes

3.1.1 Small Sample Accuracy with Ten Pump Strokes

The individual Drager indications for a small number of tubes tested at each dew point are shown in Figure 4. Detailed data are presented in Appendix A. Also shown in Figure 4 are the full agreement line and the $\pm 2^{\circ}C$ error band. In general, all points were within 2° of the true dew point. The arrows shown in Figure 4 indicate the limits for the average of the several individual determinations calculated from the manufacturer's relative standard error and the number of tubes used at the dew point under test. The individual data points lie within the manufacturer's limits indicating the average of the points to be well within the limits. These data therefore indicate that the tubes do not deviate from the manufacturer's claims and Figure 1 should be used to estimate dew points.

3.1.2 Small Sample Accuracy with Twenty Pump Strokes

The accuracy of the Drager indications for twenty pump strokes is shown in Figure 5. As recommended by Drager Inc, the dew points were calculated after dividing the scale reading (mg/L) by two since the number of strokes was twice the normal ten. At dew points of about -10°C and higher, the accuracy is poor and this is not surprising since range extension by doubling the number of strokes is suggested for dew points of about -17°C and lower.

At dew points of -15°C and lower, the twenty stroke data indicate higher dew points than do the ten stroke data but both sets of data are within 2° of the true dew point. Based on the limited data, it appears therefore that at dew points in the range -15 to -25°C, the best procedure would be to obtain both ten and twenty stroke data and average the result. However, as discussed in Appendix B, the accuracy of measurements below -15°C dew point is inferior.

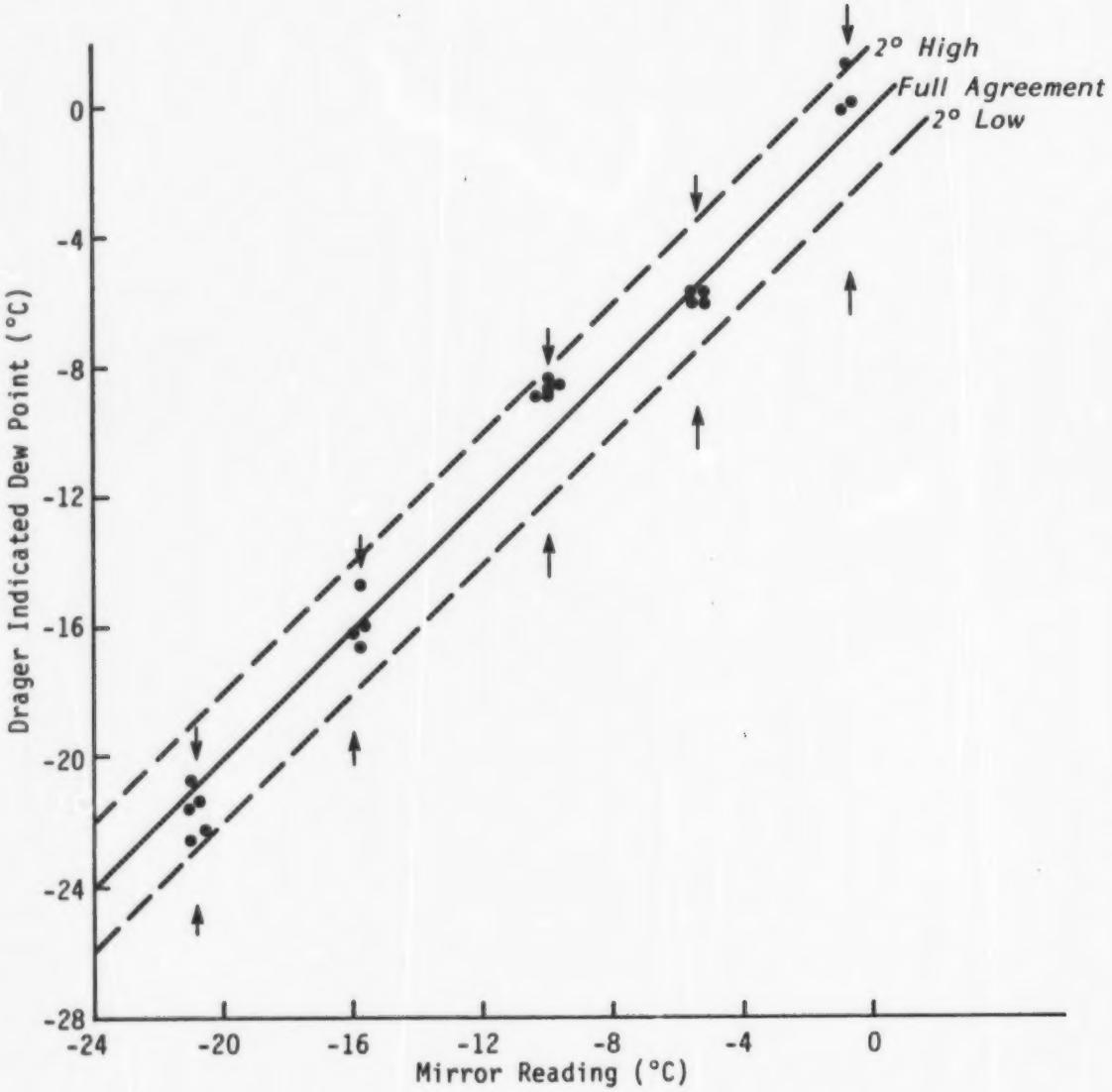

FIGURE 4

DRAGER INDICATION AT VARIOUS DEW POINTS
(TEN STROKE TEST)

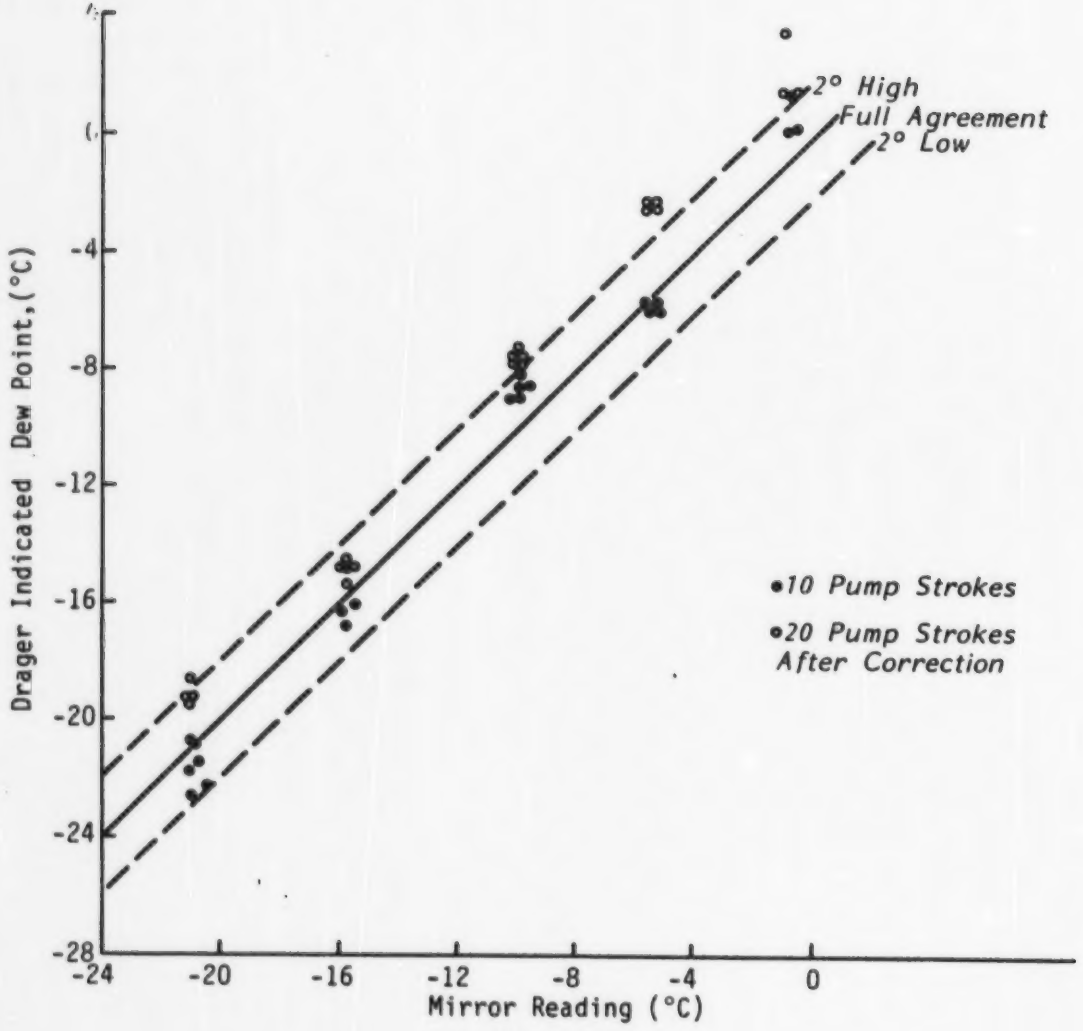

FIGURE 5

DRAGER ACCURACY AT VARIOUS DEW POINTS
(TEN AND TWENTY STROKE TESTS)
FOR THE HIGH RANGE TUBES

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3.2 Low Range Tubes

3.2.1 Relative Standard Error of Low Range Tubes

Results obtained on exposing thirty of the low range tubes to the same moisture concentration (-0.8°C dew point) are shown in Figure 6 as a histogram and in Figure 7 on a probability graph. The tests were carried out at this dew point because it is close to 0°C at which accurate dew points can be generated for checking mirror hygrometers. However, the dew point of interest is -10°C since specifications typically call for generator shutdown above -10°C. The importance of the dew point at which the test is carried out is diminished since the manufacturer claims only a small change in relative standard error (standard deviation of concentration indications divided by average indication) over the dew point range of the tube. As shown in Figures 6 and 7, the concentration values approximated a normal frequency distribution. Also, the average of the concentration values converted to dew point (-0.9°C) for the thirty tubes was in excellent agreement with the generated value of -0.8°C. Furthermore, the relative standard error of 7% was well within the 25% quoted by the manufacturer. This relative standard error is similar to that of the high range tubes. Depending on the confidence level desired for the result and the relative standard error chosen, either of Figure 1 or Figure 2 may be used to estimate dew points from readings taken with a small number of tubes.

3.2.2 Small Sample Accuracy with Two to Six Pump Strokes

The individual Drager indications for a small number of the low range tubes tested at each dew point are shown in Figure 8. Detailed data are presented in Appendix A. Also shown in Figure 8 are the full agreement and the ± 2°C accuracy lines. The two stroke data (full circles) show an acceptable accuracy of 2°C in the dew point range 0 to -16°C. This agrees with the manufacturer's lower detection limit claim of one mg/L (= -17°C d.p.) and relative standard error of 3.5°C. The four stroke data (X) also show an acceptable accuracy in the range -10°C to -20°C when the manufacturer's method of calculation is followed (Table A.4). Above -10°C (1.9 mg/L), the readings are on the high side and below -20°C the readings tend to be low. Note that the manufacturer claims a lower detection limit of -24.2°C for four strokes. Similarly, the six stroke data show acceptable accuracy in the range -17°C to -30°C or even lower and in this case, the manufacturer's suggested lower detection limit is -28°C.

Based on these limited data, it appears that the tubes do not deviate significantly from the manufacturer's claims. It is recommended therefore that two strokes be used initially in any determination. If the tube scale reading is below 1.25 mg/L (Table 1), four strokes should be used. If the reading is still below 1 mg/L, six then ten and finally twenty strokes should be tried to produce discoloration between the 1 and 2.5 mg/L scale indications on the Drager tube.

3.4 Performance in Hydrogen

To evaluate the effect of hydrogen gas on the high and low range H_2O detector tubes, tests were carried out to determine if discoloration occurred when dry hydrogen at 25°C was passed through the tubes. The hydrogen (estimated at <10 L H_2O/L or <-60°C dew point was obtained from a gas cylinder and sampling was carried out with the Drager pump using a tee in the stainless steel discharge line and a short plastic attaching tube for the Drager tube. No colour change

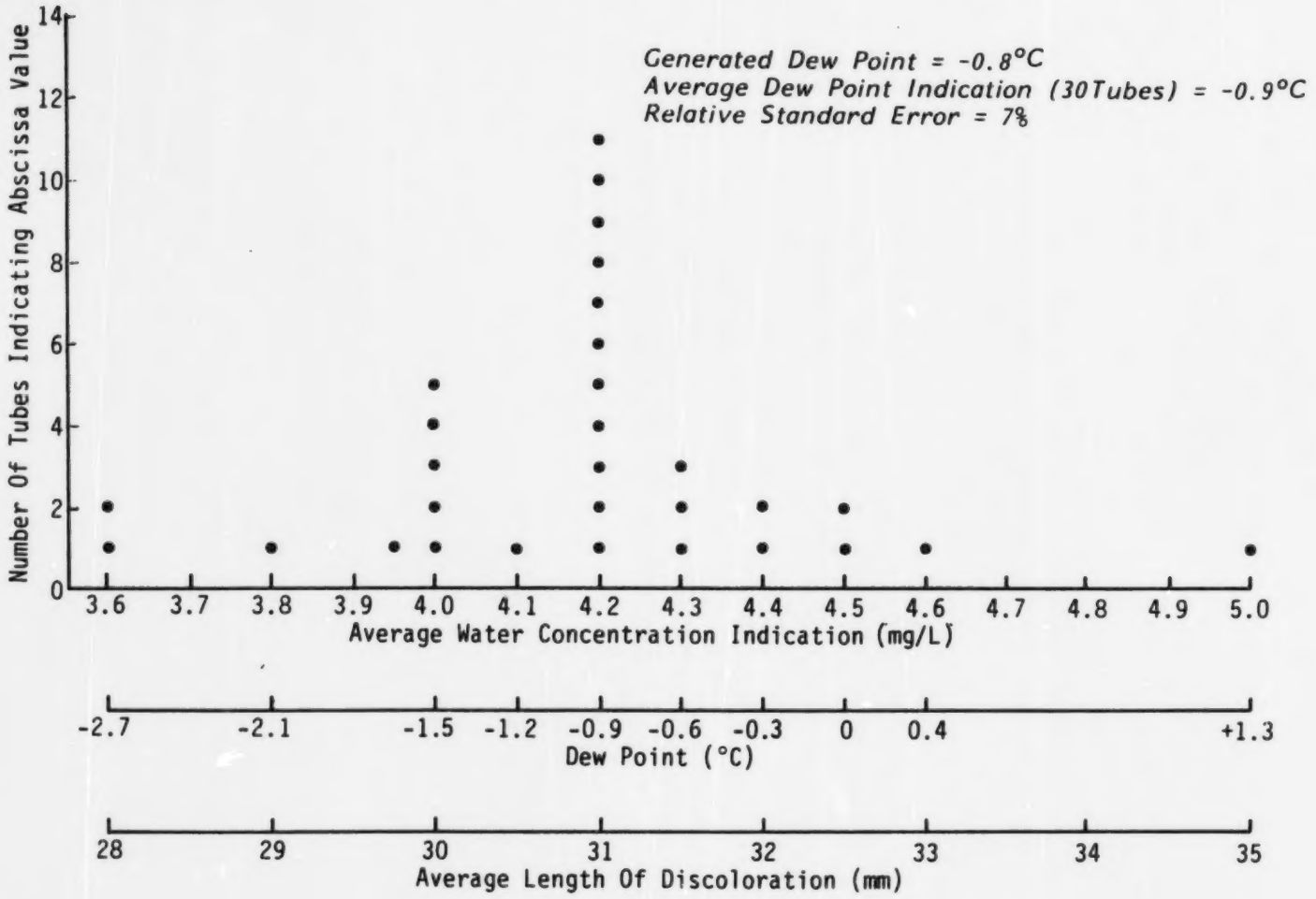
Generated Dew Point = -0.8°C
Average Dew Point Indication (30Tubes) = -0.9°C
Relative Standard Error = 7%
Number Of Tubes Indicating Abscissa Value
0
2
4
6
8
10
12
14
3.6 3.7 3.8 3.9 4.0 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5.0
Average Water Concentration Indication (mg/L)
-2.7 -2.1 -1.5 -1.2 -0.9 -0.6 -0.3 0 0.4 +1.3
Dew Point (°C)
28 29 30 31 32 33 34 35
Average Length Of Discoloration (mm)

FIGURE 6

READINGS OBTAINED FROM THIRTY TUBES
EXPOSED TO THE SAME MOISTURE CONCENTRATION

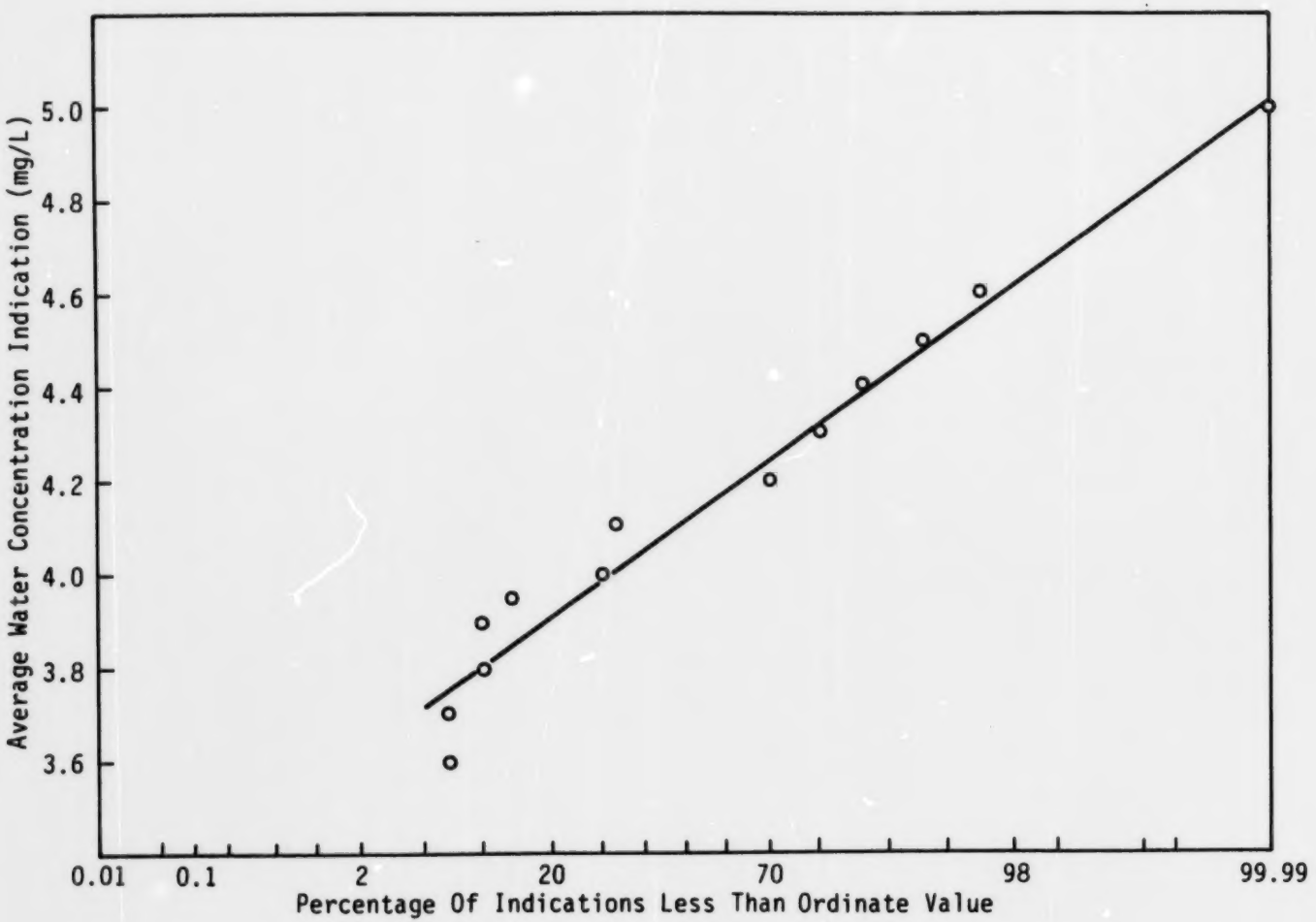

FIGURE 7

NORMAL FREQUENCY DISTRIBUTION BEHAVIOR
OF THE INDIVIDUAL TUBE READINGS

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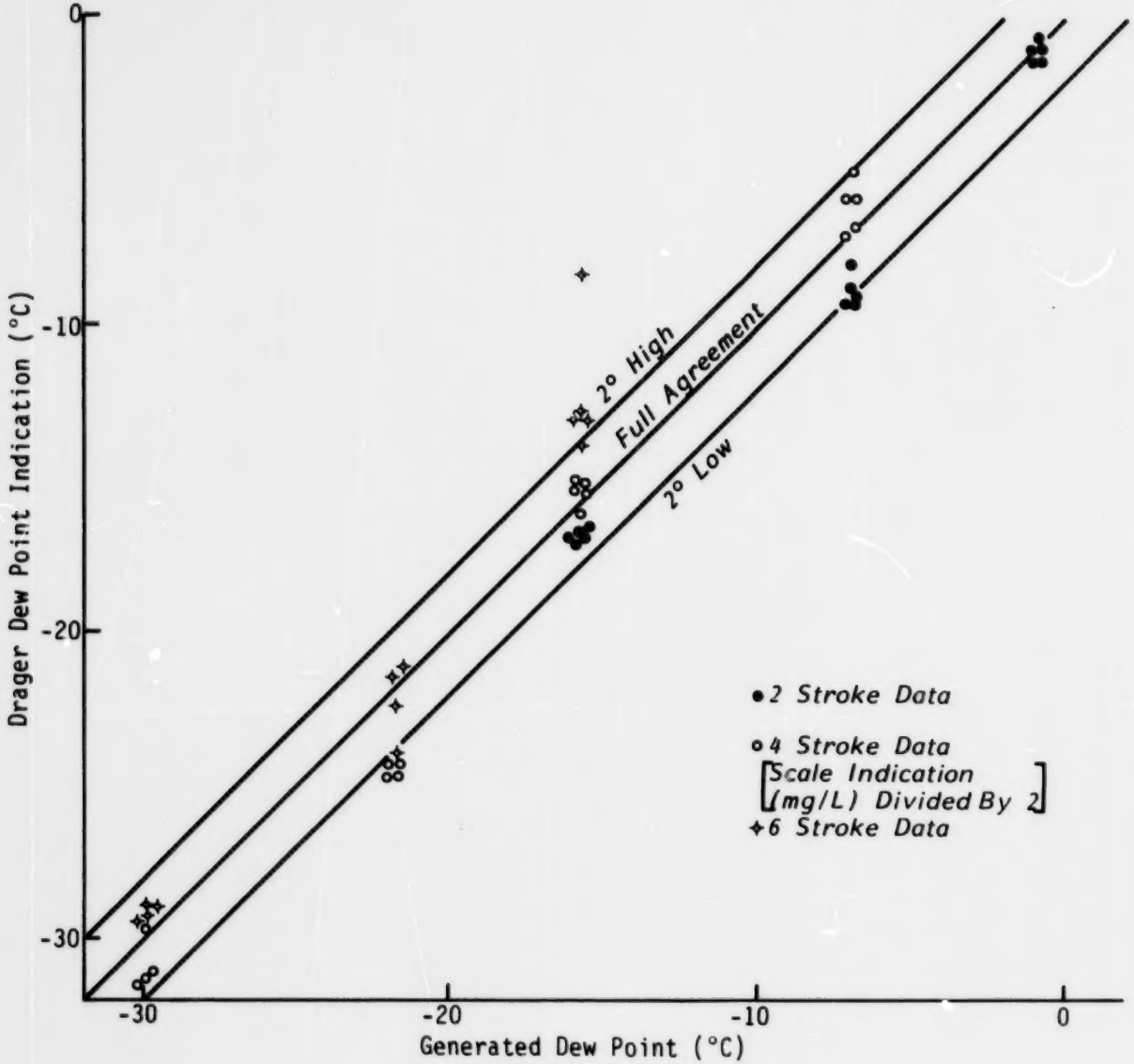

FIGURE 8
DRAGER ACCURACY AT VARIOUS DEW POINTS
FOR THE LOW RANGE TUBES

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was observed even after 100 strokes of the Drager pump lasting about six minutes for the high range tubes. Similarly, no discoloration was observed after twenty-five strokes with the low range Drager tubes. Tests were not performed with a larger number of strokes for the low range tubes. The performance of the tubes with moisture in hydrogen gas was not investigated.

4.0 CONCLUSIONS AND RECOMMENDATIONS

1. Two types of Drager tubes were tested for accuracy in determining the water vapor concentration in nitrogen. The results supported the manufacturer's claims.

2. Individual tube readings using the high range tubes showed a 2° accuracy over the dew point range 0 to $-20^{\circ}C$ with ten pump strokes. At dew points in the range -15 to $-25^{\circ}C$, the accuracy was better than 2° if both ten and twenty pump stroke data were taken and the data averaged. However, because of the limited number of tubes tested, it is recommended that Figure 1 obtained from manufacturer's data be used to obtain upper and lower limits of the dew point being measured. Alternatively, such figures give the number of tubes to be used for the desired accuracy and confidence level.

3. Concentration values obtained by exposing 30 of the low range tubes to the same moisture content approximated a normal frequency distribution. The relative standard error (standard deviation of concentration indications divided by average indication) was 7%, well within the 25% quoted by the manufacturer. Two stroke data showed an accuracy of 2° over the dew point range 0 to $-20^{\circ}C$, four stroke data showed a similar accuracy in the range -10 to $-20^{\circ}C$ d.p. and six stroke data in the range -17 to $-30^{\circ}C$ or lower. It is recommended that Figure 1 or 2 be used to establish dew point limits. It is also recommended that in any low dew point determination, an adequate number of strokes should be used to produce discolorations between the 1 and 2.5 mg/L scale indications on the low range tube. Finally, it is recommended that the high value of 25% for the relative standard error be reviewed as more experience is gained in the field with these low range tubes.

4. The major advantage of the low range tube was its capability to measure lower dew points than the high range tube. The disadvantage was the use of magnesium perchlorate which although small in quantity could explode if heated above $250^{\circ}C$ or subjected to shock. A review on whether this represents a significant hazard is recommended.

5. Tests on both high and low range tubes showed no discoloration due to dry hydrogen gas.

6. It is recommended that Matheson-Kitagawa detector tubes (magnesium perchlorate type) be evaluated since these have a normal readout range of 0.1 to 2 mg/L corresponding to a dew point range of -10 to -40°C. Only one pump stroke is required.

Approved:

M.R. Booth
Acting Manager
Chemical Research Dept

Submitted by:

V.P. Singh
Engineer, Process Development
Process Chemistry Section

Reviewed by:

S.H. Hawthorne
Unit Head, Process Development
Process Chemistry Section

kw

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3. W. May, "Drager Tube Water Vapor 1/a", Drager Review 55, June, 1985.

4. Telex, April 22, 1986, O. Hackelberg of Drager Inc to J. Ventura of Safety Supply.

5. Personal communication with Stanley J. Skea, Senior Product Application Advisor, Safety Supply Canada.

APPENDIX A

Experimental Data

Experimental data obtained with the high range tubes (CH23401) are given in Tables A.1 and A.2 while the low range tube (81 01 081) data are presented in Tables A.3, A.4 and A.5.

TABLE A.1

SUMMARY OF 10-STROKE DATA FOR HIGH RANGE TUBES CH23401

Mirror Reading (°C)	Tube No	Drager Tube Indication (mg/L)/dew point (°C)	Alternative Conditions (d)			All NIOSH Conditions Satisfied
			Average Length, L of Discolouration Per Tube (mm)	$\sigma/\bar{L}$ (b)	$\Delta L/L$	
-0.8	1	(6.0/4.2)[c]	16		Not determined	
	2	(6.0/4.2)	16		ND	Yes
	3	5.0/4.4	14		ND	based on results
	4	4.5/0.1	13	0.043	ND	at -5.4, -10.0°C
	5	4.5/0.1	13		ND	
-5.4	1	(3.5/-2.9)	12		0	
	2	2.5-3.0/-5.8	10		0.18	
	3	2.5-3.0/-5.8	10	0	0.18	yes
	4	2.5-3.0/-5.8	10		0.18	
	5	2.5-3.0/-5.8	10		0.18	
-10.0	1	2.0-2.2/-8.9	8		0.09	
	2	2.0-2.3/-8.7	8		0.14	yes
	3	2.0-2.4/-8.4	8	0.016	0.18	
	4	2.0-2.3/-8.7	8		0.14	
	5	2.0-2.3/-8.7	8		0.14	
-15.8	1	(0.5-1.0/-20.1)	4		0.67	
	2	1.0-1.2/-16.1	6		0.18	no
	3	1.0-1.5/-14.7	7	C.	0.40	
	4	0.8-1.3/-16.6	6		0.48	
	5	0.9-1.3/-16.1	6		0.36	
-20.8	1	0.5-0.7/-22.4	3		0.33	
	2	0.5-0.7/-22.4	3		0.33	no
	3	0.5-0.8/-21.6	3	0.07	0.46	
	4	0.5-0.9/-20.8	3		0.57	
	5	0.6-0.7/-21.6	3		0.15	

Notes:

(a) Negative numbers are frost points.

(b) NIOSH requirements are for a single tube with three readings being taken by three different persons. Since this was not possible, the reading of three or more tubes by the same person was substituted.

(c) Numbers in brackets discarded due to non-representative sample taken at the start of the testing.

(d) The NIOSH requirement is that one of the conditions $L > 15$ mm or $\sigma/\bar{L} < 0.1$ must be satisfied (σ is the standard deviation of $\bar{L}$). Also, $\Delta L/L$ must be less than 0.2. See Appendix B.

TABLE A.2: SUMMARY OF 20-STROKE DATA - HIGH RANGE TUBES CH23401

Mirror Reading (°C)	Tube No	Drager Indication			Average Length of Discoloration Per Tube (L)	σ/L̄	ΔL/L	All NIOSH Conditions Satisfied
		Uncorrected for Gas Volume Sampled (mg/L)	Corrected* for Gas Volume Dew Point (°C)	Corrected** for Gas Volume Dew Point (°C)				
-0.8	1	(12.0)***	(-3.5)	(4.1)	(23)			
	2	(12.0)	(-3.5)	(4.1)	(23)		Not	Yes, based
	3	10.0	-6.0	1.5	20.5		deter-	on result
	4	10.0	-4.8	1.5	21	0.036	mined	at -5.4°C
	5	11.5	-4.5	3.5	22			and -10.0
-5.4	1	(7.0)	(-11.0)	(-3.0)	(16.5)		ND	
	2	7.0 - 7.5	-10.0	-2.5	17		ND	
	3	7.0-8.0	-8.8	-2.4	17.5	0.013	0.13	
	4	7.0-8.0	-8.8	-2.4	17.5		0.13	Yes
	5	7.0-8.0	-8.8	-2.4	17.5		0.13	
-10.0	1	4.5-5.0	-17.2	-7.5	13		0.10	
	2	4.5-5.2	-15.3	-7.3	13.5		0.14	
	3	4.5-5.0	-17.2	-7.5	13	0.02	0.10	Yes
	4	4.5-4.8	-17.8	-7.7	12.5		0.06	
	5	4.5-4.8	-17.8	-7.7	12.5		0.06	
-15.8	1	(2.0-2.2)	(-21.0)	(-16.6)	(8)		0.10	
	2	2.2-2.5	-21.0	-15.4	8		0.13	Yes
	3	2.4-2.5	-20.2	-14.9	9	0.057	0.04	
	4	2.4-2.6	-20.2	-14.7	9		0.08	
	5	2.4-2.7	-20.2	-14.5	9		0.11	
-20.8	1	1.5-2.0	-21.0	-18.6	8		0.33	
	2	1.3-1.8	-22.6	-19.5	7		0.32	
	3	1.4-1.9	-22.6	-19.2	7	0.08	0.30	No
	4	1.4-1.9	-22.6	-19.2	7		0.30	
	5	1.2-1.6	-22.6	-20.8	7		0.29	

* By halving discoloration length, reading mg/L scale and converting to dew point.

** By halving scale indication (mg/L) and converting to dew point.

*** Numbers in brackets discarded.

TABLE A.3: SUMMARY OF 2-STROKE DATA FOR LOW RANGE DRAGER TUBES 81 01 081

Dew Point (°C)			Drager Tube Indication				Average Length, L of Discoloration Per Tube (mm)	$\sigma/\bar{L}$*	$\Delta L/L$**
Generated by Calculation	Reading GE	Tube No	Min	(mg/L) Max	Avg	Dew Point (°C) (Avg)			
-0.8	-0.9	1	4.0	4.3	4.2	-0.9	31	$\bar{L} = \frac{\sum_{1}^{n} L}{n}$	0.07
		2	3.9	4.5	4.0	-1.5	30		0.15
		3	4.0	4.5	4.2	-0.9	31		0.12
		4	4.0	4.4	4.3	-0.6	31.5		0.93
		5	3.6	4.7	4.0	-1.5	30	is average	0.27
		6	4.1	4.7	4.2	-0.9	31	of average	0.14
		7	4.0	4.6	4.2	-0.9	31	length of	0.14
		8	4.4	4.7	4.5	0.0	32.5	discoloration	0.07
		9	3.9	4.5	4.2	-0.9	31	= 30.9 mm	0.14
		10	4.0	4.5	4.2	-0.9	31	= -0.9°C	0.12
		11	4.0	4.5	4.2	-0.9	31	dew point	0.12
		12	3.6	4.4	4.0	-1.5	30	σ = standard	0.20
		13	3.8	3.8	3.8	-2.1	29	deviation	0
		14	4.0	4.6	4.4	-0.2	32	of L	0.14
		15	3.9	4.0	3.95	-1.6	30	= 1.4	0.02
		16	4.1	4.6	4.4	-0.3	32		0.11
		17	4.0	4.7	4.2	-0.9	31		0.17
		18	3.9	4.8	4.3	-0.6	31.5		0.21
		19	3.9	4.5	4.2	-0.9	31		0.14
		20	4.0	4.8	4.3	-0.6	31.5		0.19
		21	4.3	4.9	4.6	0.4	33		0.13
		22	4.4	4.6	4.5	0.0	32.5		0.04
		23	4.0	4.1	4.0	-1.5	30	$\frac{\sigma}{\bar{L}}$ = 0.05	0.02
		24	3.4	4.0	3.6	-2.7	28		0.17
		25	4.9	5.0	5.0	+1.3	35		0.02
		26	3.5	4.1	3.6	-2.7	28		0.17
		27	3.9	4.3	4.0	-1.5	30		0.10
		28	3.8	4.5	4.2	-0.9	31		0.17
		29	3.9	4.2	4.1	-1.2	30.5		0.07
		30	3.5	4.6	4.2	-0.9	31		0.26
-6.9	-7.3	36	2.1	2.2	2.15	-8.7	19	$\frac{\sigma}{\bar{L}}$ = 0.97	0.05
		37	2.0	2.1	2.05	-9.2	18.5	$\bar{L}$ = 19.3	0.05
		38	2.0	2.3	2.1	-9.0	19		0.14
		39	1.9	2.3	2.1	-9.0	19	$\sigma/\bar{L}$ = 0.05	0.19
		40	2.3	2.3	2.3	-7.9	21		0
-15.7	-15.0	31	1.05	1.05	1.05	-16.7	11	$\frac{\sigma}{\bar{L}}$ = 0.27	0
		32	1.05	1.1	1.05	-16.7	11	$\bar{L}$ = 10.8	0.05
		33	0.9	1.1	1.0	-17.0	10.5	$\sigma/\bar{L}$ = 0.03	0.20
		34	0.9	1.1	1.0	-17.0	10.5		0.20
		35	0.9	1.3	1.05	-16.7	11		0.38

* $\sigma/\bar{L}$ should be less than 0.1 to satisfy NIOSH requirement.

** $\Delta L/L$ should be less than 0.2 to satisfy NIOSH requirement.

TABLE A.4: SUMMARY OF 4-STROKE DATA FOR LOW RANGE DRAGER TUBE 81 01 061

Dew Point Generated (°C)	Drager Tube Indication							$\frac{\sigma}{\bar{L}}$	$\frac{\Delta L}{\bar{L}}$
	Tube No	Length of Discoloration (mm)			Reading (mg/L)	Dew Point Corrected for Gas Volume (°C)			
		Min	Max	Avg(L)		*	**		
-3.8	1	ND	ND	61***	22	-1.2	+12.9		
	2	57.5	ND	61	22	-1.2	+12.9		
	3	59	ND	60	21	-1.4	12.2	$\bar{L}$=61.45	
	4	58	ND	61	22	-1.2	+12.9		
	5	57	ND	60	21	-1.4	+12.2	σ=1.88	
	6	57	ND	61	22	-1.2	+12.9		
	7	57	ND	62	23	-0.7	+13.6	$\frac{\sigma}{\bar{L}}$=0.03	
	8	ND	ND	62	23	-0.7	+13.6		
	9	ND	ND	62	23	-0.7	+13.6		
	10	ND	ND	62	23	-0.7	+13.6		
	11	57	ND	61	22	-1.2	+12.9		
	12	56	ND	59	20	-1.7	+11.5		
	13	56.5	59	58	19	-2.0	+10.7		0.04
	14	ND	ND	62	23	-0.7	+13.6		
	15	59	ND	60	21	-1.4	+12.2		
	16	ND	ND	63	24	-0.6	+14.3		
	17	ND	ND	63	24	-0.6	+14.3		
	18	59	ND	62	23	-0.7	+13.6		
	19	59	ND	61	22	-1.2	+12.9		
	20	ND	ND	63	24	-0.6	+14.3		
	21	ND	ND	67	28	+0.7	+16.7		
	22	ND	ND	65	26	-0.1	+15.5		
	23	ND	ND	61	22	-1.2	+12.9		
	24	56.5	59	57	18	2.0	+ 9.9		0.04
	25	ND	ND	ND	-	NA	-		
	26	56.5	ND	61	22	-1.2	+12.9		
	27	ND	ND	61	22	-1.2	+12.9		
	28	58	ND	62	23	-0.7	+13.6		
	29	ND	ND	62	23	-0.7	+13.6		
	30	56.5	ND	62	23	-0.7	+13.6		
-6.9	36	35	38.5	37	5.5	-9.5	-5.8	$\bar{L}$=37.0	0.09
	37	34	38.5	36	5	-10.0	-6.9		0.13
	38	35	38.5	37	5.5	-9.5	-5.8	σ= 1.22	0.09
	39	33.5	39	36	5	-10.0	-6.9	$\frac{\sigma}{\bar{L}}$=0.03	0.15
	40	37.5	39.5	39	6.0	-8.5	-4.9		0.05
-15.7	31	21	21	21	2.4	-17.1	-15.2	$\bar{L}$=20.8	0.0
	32	21	21	21	2.4	-17.1	-15.2	σ=0.45	0.0
	33	18.5	23	21	2.4	-17.1	-15.2	σ=0.02	0.21
	34	19.5	21.5	20	2.2	-18.2	-16.1		0.10
	35	20	23.5	21	2.4	-17.1	-15.2		0.17
-21.8	36	11	11	11	1	-35.4	-24.5	$\bar{L}$=11.00	0
	37	11	11	11	1	-35.4	-24.5	σ=0	0
	38	11	11	11	1	-35.4	-24.5	σ=0	0
	39	11	11	11	1	-35.4	-24.5		0
-30.0	40	6	6	6	0.5	poor	-31.3	$\bar{L}$=6.25	0
	41	6	6	6	0.5	read-	-31.3	σ=0.50	0
	42	7	7	7	0.6		-29.7	σ	0
	43	6	6	6	0.5		-31.3	$\frac{\sigma}{\bar{L}}$= 0.08	0

* by halving discoloration length, reading mg/L scale and converting to dew point.
** By halving scale indication (mg/L) and converting to dew point (as recommended by Drager).
*** Full scale indication = 20 mg/L occurs 59 min from the zero point. Concentrations for longer discolorations were estimated.

ND Not determined.

TABLE A.5: SUMMARY OF SIX-STROKE DATA FOR LOW RANGE DRAGER TUBE 81 01 081

Dew Point Generated (°C)	Tube No.	Drager Tube Indication Length of Discoloration (mm)			Reading (mg/L)	Dew Point* Corrected for Gas Volume (°C)	σ/L̄	ΔL/L
		Min.	Max.	Avg(L)				
-6.9	36	51	57	55	15.5	+1.9	$\bar{L}$=55.1	0.11
	37	53	57	54.5	15	+1.3	σ=1.14	0.07
	38	53.5	57	55	15.5	+1.9	σ=0.02	0.06
	39	50	57	54	13.5	0.0	$\bar{L}$	0.13
	40	56.5	58	57	17.5	+3.8		0.03
-15.7	31	30.5	30.5	30.5	4.1	-13.9	$\bar{L}$=31.6	0.0
	32	30.5	31	31	6.7	-8.3	σ=0.82	0.02
	33	30.5	35.5	32	4.4	-13.1	σ=0.03	0.16
	34	29.5	37.5	32	4.4	-13.1	$\bar{L}$	0.25
	35	32.0	35.5	32.5	4.5	-12.7		0.11
-21.7	36	19	19	19	2	-21.3	$\bar{L}$=17	0.0
	37	19	19	19	2	-21.3	σ=2.45	0.0
	38	14	14	14	1.5	-24.3	σ=0.14	0.0
	39	15	16	16	1.8	-22.4	$\bar{L}$	0.06
-30.0	40	8	10	9	0.9	-29.3	$\bar{L}$=9.25	0.22
	41	8	10	9	0.9	-29.3	σ=0.5	0.22
	42	8	9	9	0.9	-29.3	σ=0.05	0.11
	43	10	10	10	0.95	-28.9	$\bar{L}$	0.0

* by dividing scale indication (mg/L) by three (G/2) and converting to dew point.

TABLE A.6: SUMMARY OF TEN-STROKE DATA FOR LOW RANGE DRAGER TUBE 81 01 081

Dew Point Generated (°C)	Tube No.	Drager Tube Indication Length of Discoloration (mm)			Reading (mg/L)	Dew Point Corrected for Gas Volume (°C)	$\sigma/\bar{L}$	$\Delta L/L$
		Min.	Max.	Avg(L)				
-21.8	36	31	31	31	4	-19.5		0
	37	31	31	31	4	-19.5	0.07	0
	38	23	31	27	3	-22.4		0.3
	39	31	31	31	4	-19.5		0
-30.0	40	12	17	16	1.6	-28.6		0.31
	41	14	14	14	1.3	-30.6	0.09	0
	42	11	14	13	1.2	-31.2		0.20
	43	14	14	14	1.3	-30.6		0

APPENDIX B

NIOSH Criteria

Criteria for Acceptable Readings

The National Institute for Occupational Safety and Health (NIOSH) has specified criteria for acceptable readings from detector tubes used for hazardous vapours. These criteria which may be applied to the water detector tubes investigated in this study are:

1(a) the length of the discoloration should be at least 15 mm

or

1(b) the standard deviation of the detector tube indications obtained by three or more independent persons must be less than 10% of the mean detector indication

and

2. the difference between the longest and shortest discoloration length for a given tube must be less than 20% of the mean discolored length

Examination of the ten stroke pump data for the high range tubes (Table A.1, Appendix A) indicates that the NIOSH criteria were satisfied at dew points above about -10°C but not at -16°C and lower. On increasing to twenty pump strokes (Table A.2), the NIOSH criteria were satisfied at a lower dew point of -16°C but not below. These data suggest that dew points between -10 and -16°C should be measured with twenty strokes to achieve reliabilities similar to those acceptable to NIOSH.

Examination of the two stroke data for the low range tubes indicates that NIOSH criteria would probably be satisfied at dew points above about -10°C. Corresponding values for 4 and 6 strokes are about -16°C and -22°C, respectively. These data are compared in Table B.1 with values from Figure 8 in which a 2°C accuracy was observed. To conform to NIOSH criteria and a 2° accuracy, therefore, two strokes should be used in the dew point range 0 to -10°C (4.5 - 1.9 mg/L), four strokes in the range -10 to -16°C (1.9 - 1.1 mg/L or for scale readings 3.8 - 2.2 mg/L) and six strokes in the dew point range -17 to -22°C (1.0 - 0.64 mg/L or for scale readings 3.0 - 1.95 mg/L).

TABLE B.1

Dew Point Ranges for 2° Accuracy and Conformance with NIOSH Criteria
Low Range Tube 81 01 081

Number of Strokes	Dew Point Range Over Which 2°C Accuracy Observed (Figure 8)	Dew Point Range Over Which NIOSH Criteria Satisfied
2	0 to -16°C	above -10°C
4	-10 to -20°C	above -16°C
6	-17 to -30°C	above -22°C

APPENDIX C

Tube Data

CH23401

OPERATING INSTRUCTIONS

DRÄGER Tube
Water Vapour 0.1

1. General and Application

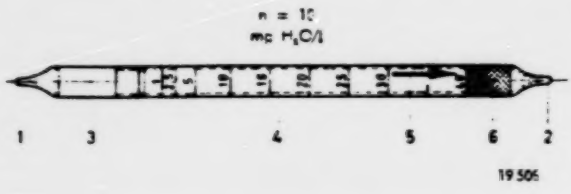
This tube is used for the climatic monitoring of workrooms, cold-storage rooms, etc.

For the use of DRÄGER Tubes and Gas Detector, refer to Operating Instructions 2341 e

2. Description

Refer to illustration

"Opening period" (time needed for the release of the compressed bellows, ending when the arrestor chain is fully tensioned): maximum of 3 seconds, the maximum being twice that.



1 and 2 fused tips
3 writing surface
4 indicating layer (yellow) with scale calibrated in mg per litre, valid for n = 10 (n = number of strokes)
5 arrow (must point towards the pump during the test)
6 covering film (red)

3. Measuring Range (20° C, 1013 mbar)

With 10 strokes: approx. 0.1 mg/litre up to 40 mg H_2O/litre.

The first scale line on the printed scale corresponds to 1 mg H_2O per litre; with the 10 stroke test smaller concentrations are to be estimated only.

4. Test and Evaluation of the Result

With 10 strokes of the pump, draw the air sample through the DRÄGER Tube. The length of the red to brown discolouration corresponds to the concentration (mg H_2O/litre). Accurate measurements are possible only as long as water **vapour** is present. Water **mists** indicate invalid results, therefore avoid condensation between the gas sample and the DRÄGER Tube. For evaluation — e.g. the conversion to relative humidity, refer to Information Sheet No. 27.

5. Remarks

After a positive result, the DRÄGER Tube cannot be reused for concentration determinations. Discolourations lost for some time providing the tubes are sealed after the test. DRÄGER Tubes may then be retained as evidence.

6. Influence of the Temperature on the Measurement

The calibrated scale printed on the DRÄGER Tube is valid for 10 strokes of the pump if both Tube and gas sample are within 0° C and 40° C. If temperatures are below 0° C, the scale is valid for 11 strokes.

7. Specificity

The indication is based on a colour reaction with selenium-sulfuric acid. Colour change is from yellow to red. Indication is characteristic for water vapour. Interferences caused by volatile alcohols. Some organic vapours, e.g. hydrocarbons, also discolour the indicating layer (different colours). Water vapour determination is then not possible.

8. Predetermined Period of Use

Two years at storage temperatures below 30° C. The lower the temperature at which the DRÄGER Tubes are stored, the smaller the change in their chemical properties.

Water vapour content of moisture-saturated air (relative air humidity = 100%) at various temperatures.

temperature °C	mg H_2O/l	temperature °C	mg H_2O/l
0	4.8	25	23.0
5	6.8	27	25.8
8	8.3	30	30.3
10	9.4	32	33.7
15	12.8	36	42.0
17	14.5	38	46.0
20	17.3	40	51.0
22	19.4		

Our **table 2340 e** contains in alphabetical order **the gases and vapours** measurable with DRÄGER Tubes, important **physical and toxicological data** of the gases and vapours as well as many references to literature.

This table will be sent to you on request.

Caution

Do not allow the DRÄGER Tubes to fall into the hands of children.

Contents are corrosive.

For destroying the DRÄGER Tubes, refer to Information Sheet No. 88

DRÄGERWERK · AG · LÜBECK

Telephone: 882-1 Telex: 02 6807

13th Edition 234—234 e December 1978

1 DRÄGER Tube Water Vapour 0.1 (CH 23401)

2 Standard range of measurement (20°C, 1013 mbar)	0.1 to 40 mg water vapour per litre (The first division of the printed scale corresponds to 1 mg/litre, lower concentrations can only be estimated in the 10-stroke test)
3 Number of strokes of the DRÄGER gas detector pump	n = 10
4 Relative standard deviation	15 to 10%

5 Description

Scale tube • yellow indicating layer, reagent: activated selenium dioxide and sulphuric acid • colour change to reddish brown.

6 Reaction principle

H_2O Water vapour	+	SeO_2 Selenium dioxide	+	H_2SO_4 Sulphuric acid	→	Reddish brown reaction product

7 Cross-sensitivity

Unsaturated hydrocarbons, present in fairly high concentrations, change the colour of the entire indicating layer to a diffuse brown.

8 Extension of the range of measurement

8.1 Concentrations of up to 160 mg H_2O per litre can be measured using the method below:
Heat the water vapour detector tube to about 70°C and keep it at this temperature during measurement. Suck the gas sample through the tube with 2 pump strokes. The scale value read-off multiplied by a factor of 4 gives mg H_2O per litre. Standard deviation app. 25%.

8.2 With 20 strokes, multiply the indication by a factor of 0.5. The range of measurement then extends up to 20 mg H_2O per litre.

1 General and Application

This DRÄGER-Tube is designed to be used for measuring the water vapour concentration in natural gas. It may also be used for climatic monitoring of e.g. workrooms, cold-storage rooms, etc.

The DRÄGER-Tube is to be used in conjunction with the DRAGER-gas detector (see operating instructions 4314e). It is not allowed to use this tube together with pumps of other manufacturers, because large measuring errors may occur. Such a combination would be against official regulations.

2. Description

See illustration

Opening time (duration of one pump stroke until the limit chain is totally tensioned) 10 to 20 s.

3. Measuring Range (20 °C ≙ 68 °F, 1013 mbar)

With 2 strokes 1 to 20 mg H_2O/L. An extension of measuring range is possible with additional pump strokes. The lower detection limit then is approx. 100 mg H_2O/m^3. The scale value is to divide by half of the stroke number, e.g. with 4 strokes (concentration range 0.5 to 1 mg/L) division by 2, with 10 strokes (concentration range 0.2 to 0.5 mg/L) division by 5, below 0.2 mg/L (n=20) division by 10. We recommend to cool the tube while extending the measuring range with additional pump strokes.

4. Test and Evaluation of the Result

Draw the gas to be investigated with 2 pump strokes through the DRAGER-tube. The length of the turkish-blue discolouration corresponds to the concentration (mg H_2O per litre).

Accurate measurements are only possible as long as water vapour is present. Avoid condensation between gas sample and DRÄGER-tube.

5. Remarks

After positive result, the DRÄGER-tube cannot be used for further measurements. Discolouration lasts for some days, if the DRÄGER-tube is closed with rubber caps.

6. Influence of the Temperature on the Measurement

The calibrated scale printed on the DRÄGER-tube is valid for 2 pump strokes, if tube and gas sample are between 0 °C (≙ 32 °F) and 40 °C (≙ 104 °F).

7. Specifity

Indication is based on the colour reaction with magnesium perchlorate/acid-base-indicator. No influence of the indication by e.g. 1000 ppm nitrogen dioxide, 4000 ppm sulfur dioxide, 100 ppm hydrochloric acid, 2000 ppm ethanol, 2000 ppm acetone, 500 ppm ammonia, 3000 ppm hydrogen sulfide.

8. Storage temperature and shelf life

see label of the box

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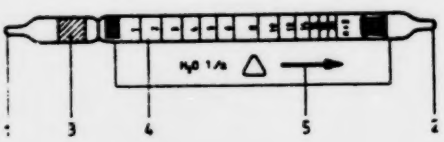
water vapour content of moisture-saturated air (relative humidity = 100 %) at different temperatures

Temperature °C/°F	mg H_2O/L
0 / 32	4.8
5 / 41	6.8
10 / 50	9.4
15 / 59	12.8
20 / 68	17.3
25 / 77	23.0
30 / 86	30.3
40 / 104	51.0



1 and 2 fused tips
3 writing surface
4 indicating layer (yellow) with scale calibrated in mg per litre, valid for n = 2 strokes
5 arrow (must point towards the pump during the test)

Water vapour 1/a

DETECTOR TUBE HANDBOOK

Compiled by Kurt Leichnitz

1	Gases and vapours to be measured	Water vapour
2	Chemical formula	H_2O
3	DRÄGER Tube to be used	Water vapour
4	Threshold limit value (1981 position)	—
5	Threshold of smell (app.)	—
6	1 ppm ≙ . . . (20°C, 1013 mbar)	0.75 mg/m³
7	1 mg/m³ ≙ . . . (20°C, 1013 mbar)	1.33 ppm
8	Molecular weight	18.01
9	Vapour pressure (at 20°C)	23.3 mbar
10	Volatility (at 20°C)	17.3 mg/l
11	Lower ignition limit	—
12	Upper ignition limit	—
13	Flash point	—
14	Group and hazard class (VbF)	—
15	Ignition temperature	—
16	Evaporation factor (ether = 1)	—
17	Boiling point (at 1013 mbar)	100°C
18	Density (liquid, 20°C)	0.998 g/cm³
19	Respirator filter, code letter and colour	—

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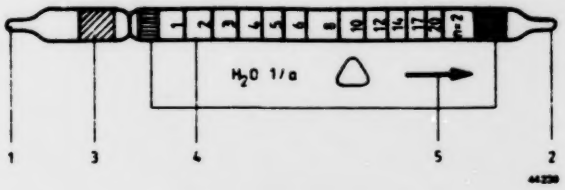
DRÄGER Tube Water Vapor 1/a — 81 01 081

OPERATING INSTRUCTIONS 234-010810 · 1st Edition · March 1985

1 General and Application
This DRAGER-Tube is designed to be used for measuring the water vapor concentration in natural gas. It may also be used for climatic monitoring of e.g. workrooms, cold-storage rooms, etc.
The DRAGER-Tube is to be used in conjunction with the DRAGER-gas detector (see operating instructions 4341e). It is not allowed to use this tube together with pumps of other manufacturers because large measuring errors may occur. Such a combination would be against official regulations.

2 Description
See illustration.
Opening time (duration of one pump stroke until the limit chain is totally tensioned) 10 to 20 s.



1 and 2 fused tips
3 writing surface
4 indicating layer (yellow) with scale calibrated in mg per litre, valid for n = 2 strokes
5 arrow (must point towards the pump during the test)

3 Measuring range (20°C = 68°F, 1013 mbar)
With 2 strokes 1 to 20 mg H_2O/L. An extension of measuring range is possible with additional pump strokes. The lower detection limit then is approx. 500 mg H_2O/m^3.
The numeric value of scale is to divide by half of the stroke number, i.e. with 4 strokes (concentration range 0.5 to 1 mg/L) division by 2.

4 Test and Evaluation of the Result
Before each measurement test the pump for tightness using an unopened tube. Break-off the tips of the DRAGER-Tube. Insert the DRAGER-Tube tightly in the pump head (arrow points towards the pump). Draw the gas to be investigated with 2 pump strokes through the DRAGER-tube. The length of the turkish-blue discolouration corresponds to the concentration (mg H_2O per litre). Accurate measurements are only possible as long as water vapour is present. Avoid condensation between gas sample and DRAGER-tube.

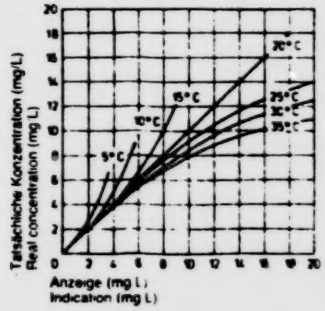
5 Remarks
After positive result, the DRAGER-tube cannot be used for further measurements. Discoloration lasts for some days, if the DRAGER-tube is closed with rubber caps.

6 Influence of the Temperature on the Measurement
The calibrated scale printed on the DRAGER-tube is valid for 2 pump strokes at 20°C. Other temperatures refer to diagramme.

7 Specifity
Indication is based on the colour reaction with magnesium perchlorate/acid-base-indicator. No influence of the indication by e.g. 1000 ppm nitrogen dioxide, 4000 ppm sulfur dioxide, 100 ppm hydrochloric acid, 2000 ppm ethanol, 2000 ppm acetone, 500 ppm ammonia, 3000 ppm Hydrogen sulfide, 500 ppm THT, 500 ppm mercaptane (R-SH).

8 Storage temperature and shelf life
See label of the box.

Temperature correction for 2 strokes with bellows pump:



Water vapour content of moisture-saturated air (relative humidity = 100%) at different temperatures

Temperatur Temperature °C/°F	mg H_2O/L
0 / 32	4.8
5 / 41	6.8
10 / 50	9.4
15 / 59	12.8
20 / 68	17.3
25 / 77	23.0
30 / 86	30.3
40 / 104	51.0

Our table 4340e contains in alphabetical order those gases and vapours which can be measured with DRAGER-tubes, important physical and toxical and toxicological data of the gases and vapours as well as references to the literature.
This table will be sent to you on request.

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Caution!
Do not allow the used DRAGER-tubes to fall into the hands of children.

Contents are corrosive.

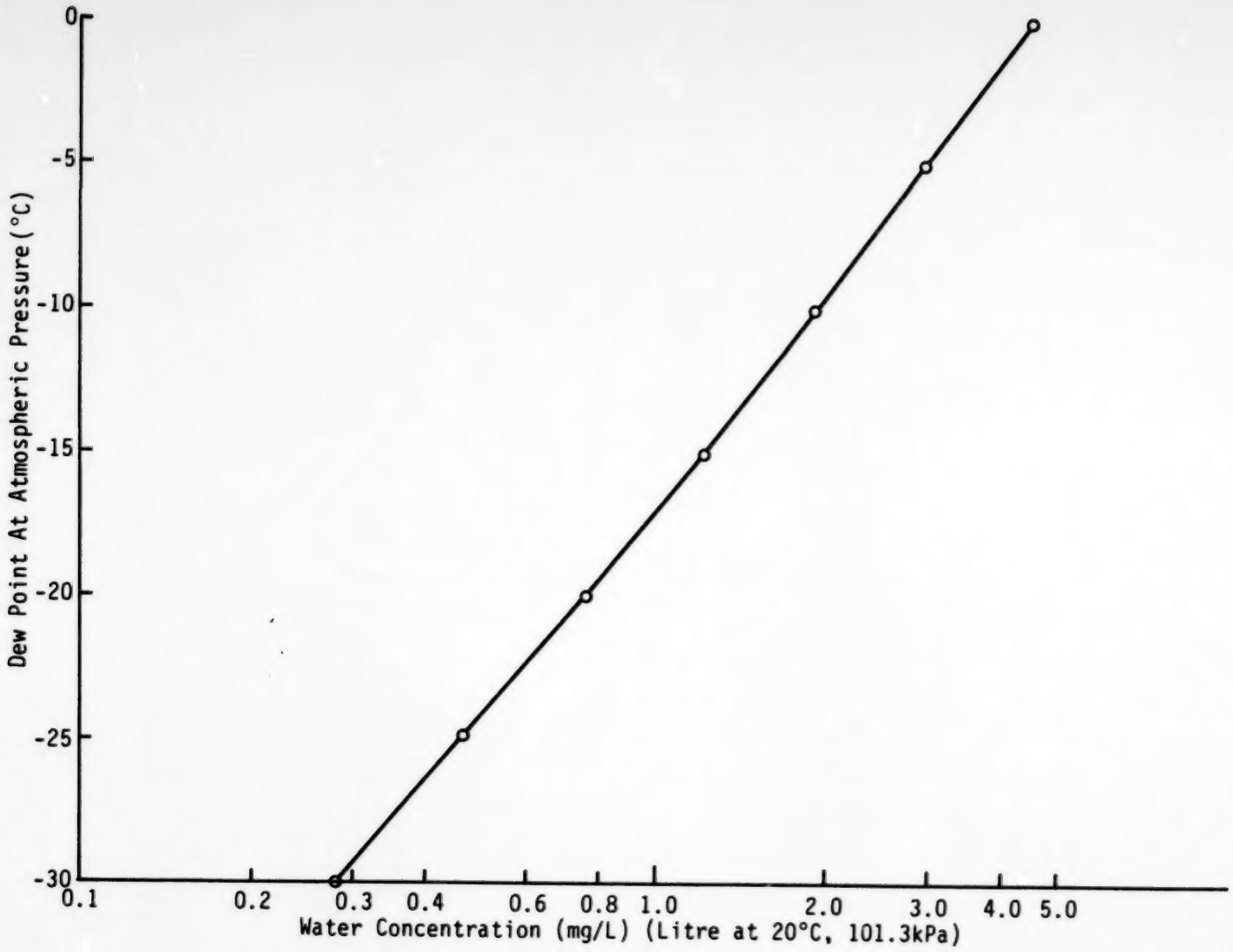

FIGURE 9

CONVERSION OF WATER CONCENTRATION
(mg/L) TO DEW POINT (°C)

173395-RD
86-338

APPENDIX D

Statistical Information

The Students' t is defined as $t = (\bar{x}-\mu)/(s/\sqrt{n})$ where $\bar{x}$ is the average of the n samples, μ is the population average and s is the standard deviation of $\bar{x}$.

If $d = \frac{(\bar{x}-\mu)}{\bar{x}}$ is the accuracy, then the above equation can be rearranged to give

$$d^2 = \frac{t^2 \, (s/\bar{x})^2}{n}$$

where $s/\bar{x}$ is the relative standard error. The manufacturer claims it is 0.15 at the low end of the scale for the high range tubes. For a 99.9% level of confidence, statistical tables give t = 3.291. Hence the accuracy d can be calculated for different values of n allowing a concentration and corresponding dew point range to be obtained.

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